- optical, surgical, photographic, and other instruments;
- electronic components;
- communication equipment; and
- scientific and mechanical measuring instruments. (See text table 2-12 and appendix table 2-50.)

Among these sectors, the highest R&D intensity (38.5 percent in 1997) is observed in research, development and testing services (which is not surprising because, in this special case, R&D is the actual product sold rather than a means toward acquiring a better product or production process). Computer data and processing services are second, at 13.3 percent, followed by drugs and medicines at 10.5 percent.[24] The "office, computing, and accounting machines" sector had an R&D intensity as high as 12.3 percent in 1987, but its R&D intensity fell to 9.2 percent by 1997.

Text table 2–12.
Company and other (except Federal) industrial R&D funds as a percentage of net sales in R&D-performing companies for selected industries: 1987 and 1997

Industry and size of company	1987	1997
Manufacturing		
Drugs and medicines	8.7	10.5
Office, computing, and accounting machines.	12.3	9.2
Optical, surgical, photographic, and other instruments.	7.2	8.9
Electronic components	8.5	8.1
Communication equipment	5.5	8.0
Scientific and mechanical measuring instruments	8.1	6.5
Aircraft and missiles	3.6	3.9
Motor vehicles and motor vehicles equipment	3.4	3.8
Industrial chemicals	4.4	3.5
Other machinery, except electrical	3.0	3.0
Other electrical equipment	2.6	2.7
Radio and TV receiving equipment.	3.2	2.6
Other transportation equipment	2.5	2.2
Other chemicals	3.3	2.1
Stone, clay, and glass products	2.5	1.8
Fabricated metal products	1.2	1.5
Rubber products	1.6	1.4
Paper and allied products	0.6	1.1
Lumber, wood products, and furniture	0.6	0.9
Textiles and apparel.	0.4	0.9
Nonferrous metals and products	1.3	0.6
Petroleum refining and extraction	1.0	0.6
Ferrous metals and products	0.6	0.6
Food, kindred, and tobacco products	0.6	0.5
Nonmanufacturing		
Research, development, and testing services	5.5	38.5
Computer and data processing services	NA	13.3
Engineering, architectural, and surveying.	NA	2.6
Trade.	NA	2.4
Finance, insurance, and real estate.	NA	0.7
Telephone communications	NA	0.7
Electric, gas, and sanitary services	NA	0.1

NA = not available

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Survey of Industrial Research and Development, 1997*

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Sectors that were lowest in R&D intensity in 1997 included

- nonferrous metals and products;
- petroleum refining and extraction;
- ferrous metals and products;
- food, kindred, and tobacco products; and
- electric, gas, and sanitary services.

These sectors, in large part, reflect the "smokestack industries" that played a dominant role in the U.S. economy in the mid-1900s in terms of new directions of technological change.

Performance by Geographic Location, Character of Work, and Field of Science

R&D by Geographic Location

The latest data available on the state distribution of R&D performance are for 1997.[25] These data cover R&D performance by industry, academia, and Federal agencies, as well as Federally funded R&D activities of nonprofit institutions. The state data on R&D cover 52 records: the 50 states, the District of Columbia, and "other/unknown" (which accounts primarily for R&D for which the particular state was not known). Approximately two-thirds of the R&D that could not be associated with a particular state is R&D performed by the nonprofit sector. Consequently, the distribution of R&D by state indicates primarily where R&D is undertaken in Federal, industrial, and university facilities.

In 1997, total R&D expenditures in the United States were $211.3 billion, of which $199.1 billion could be attributed to expenditures within individual states; the remainder was "other/unknown." (See appendix table 2-20.) The statistics and discussion below refer to state R&D levels in relation to the distributed total of $199.1 billion.

R&D is concentrated in a small number of states. In 1997, California had the highest level of R&D expenditures performed within its borders ($41.7 billion, representing approximately one-fifth of U.S. total). The six states with the highest levels of R&D expenditures—California, Michigan, New York, New Jersey, Massachusetts, and Texas (in descending order)—accounted for approximately half of the entire na-

[24]R&D outlays in the semiconductor equipment and materials industry are estimated to be about 12–15 percent of sales (Council on Competitiveness 1996). The broad industry classification system used in NSF's industrial R&D survey can mask pockets of high-tech activity.

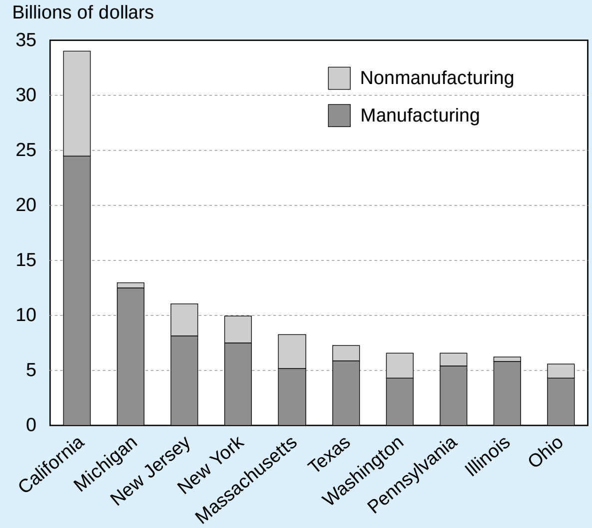
[25]Although annual data are available on the location of R&D performance by the academic and Federal sectors, until recently, NSF has conducted surveys on the state distribution of industrial R&D performance only in odd-numbered years. At this writing, the 1998 industry R&D survey data have not been processed, making 1997 the most recent year for which the state-specific R&D totals can be reported.

tional effort. The top 10 states—the six states listed above plus (in descending order) Pennsylvania, Illinois, Washington, and Maryland—accounted for approximately two-thirds of the national effort. (See appendix table 2-20.) California's R&D performance exceeded by a factor of three the next-highest state, Michigan ($14.0 billion). After Michigan, R&D levels decline relatively smoothly to approximately $7.4 billion for Maryland. The 20 highest-ranking states in R&D expenditures accounted for about 86 percent of the U.S. total; the lowest 20 states accounted for 4 percent.

States vary widely in the size of their economies owing to differences in population, land area, infrastructure, natural resources, and history. Consequently, variation in the R&D expenditure levels of states may simply reflect differences in economic size or the nature of their R&D efforts. A simple way of controlling for this "size effect" is to measure each state's R&D level as a proportion of its gross state product (GSP). (See appendix table 2-52.) As with the ratio of industrial R&D to sales, the proportion of a state's GSP devoted to R&D is referred to as R&D "intensity." Overall, the Nation's total R&D to GDP ratio in 1997 was 2.6 percent in 1997. The top 10 states with regard to R&D intensity were (in descending order) New Mexico (6.7 percent), the District of Columbia (5.3 percent), Michigan (5.1 percent), Massachusetts (5.0 percent), Maryland (4.8 percent), Washington (4.4 percent), Idaho (4.4 percent), New Jersey (4.1 percent), California (4.0 percent), and Rhode Island (3.7 percent). New Mexico's high R&D intensity is largely attributable to Federal support (provided by the Department of Energy) for the Sandia National Laboratories and Los Alamos National Laboratory FFRDCs in the state.[26]

States have always varied in terms of the levels and types of industrial operations they contain. Thus, they vary as well in the levels of R&D they contain by industrial sector. One measure of such variation among states is the extent to which their industrial R&D is in the nonmanufacturing sector as opposed to the manufacturing sector. Among the top 10 states in 1997 in industrial R&D performance, California, New Jersey, New York, Massachusetts, and Washington all had relatively high levels of R&D in the nonmanufacturing sector (25 percent or more of the total). (See figure 2-14.) Michigan, Texas, Pennsylvania, Illinois, and Ohio had lower levels of R&D in nonmanufacturing, as a percentage of the total.

Figure 2-14.
Industrial R&D performance in the top 10 states in industrial R&D in 1997: R&D in manufacturing and nonmanufacturing



NOTE: These levels include R&D performed by industry-administered FFRDCs.

SOURCE: National Science Foundation, Division of Science Resources Studies (NSF/SRS), *Survey of Industrial Research and Development, 1997*

See appendix table 2-20. *Science & Engineering Indicators – 2000*

Trends in National R&D by Character of Work

The traditional way to analyze trends in R&D performance is to examine the amount of funds devoted to basic research, applied research, and development. (See sidebar, "Definitions.") These terms are convenient because they correspond to popular models that depict innovation occurring in a linear progression through three stages: (1) scientific breakthroughs from the performance of basic research lead to (2) applied research, which leads to (3) development or application of applied research to commercial products, processes, and services.

The simplicity of this approach makes it appealing to policymakers, even though the traditional categories of basic research, applied research, and development do not always ideally describe the complexity of the relationship between science, technology, and innovation in the real world.[27] Additionally, many analysts argue that the distinctions between basic research and applied research are becoming increasingly blurred. Nonetheless, these general categories are generally useful to characterize the relative expected time horizons and types of investments.

The United States spent $37.9 billion on the performance of basic research in 1998, $51.2 billion on applied research, and $138.1 billion on development. (See figure 2-15.) These

[26]For additional information about the geographic distribution of R&D within the United States, see NSF, "Science and Engineering State Profiles: 1999," by R. Bennof and S. Payson, forthcoming.

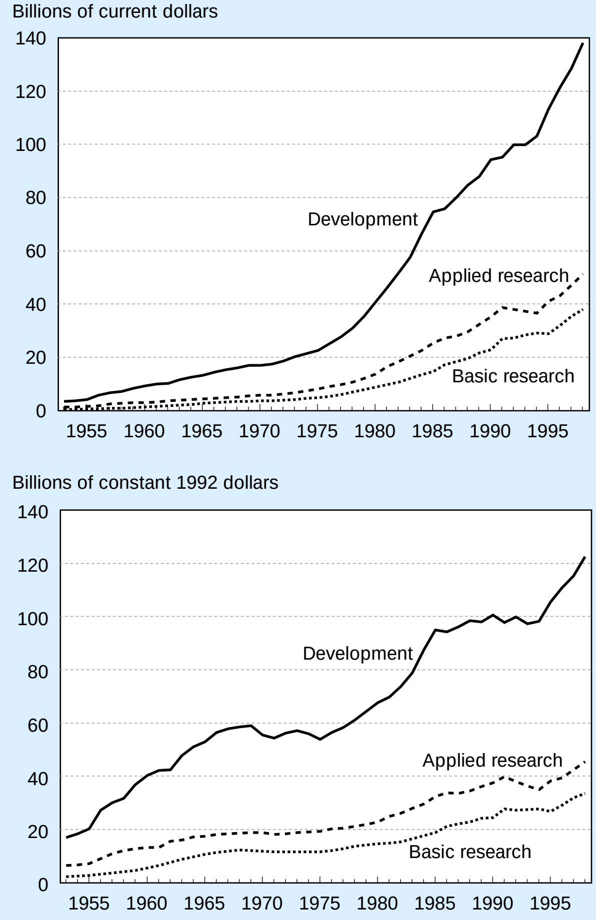
[27]See NSB (1996), chapter 4, "Alternative Models of R&D and Innovation." According to the Council on Competitiveness (1996), "The old distinction between basic and applied research has proven politically unproductive and no longer reflects the realities of the innovation process…The United States [should adopt] a new and more up-to-date vocabulary, one that accounts for changing calculations of R&D risk and relevance over short-, medium- and long-term horizons." In its report, the Council identified three types of research (short-term/low-risk, mid-term/mid-risk, and long-term/high-risk) and the economic sectors that have primary and secondary responsibility for each. In contrast, another study found that R&D managers/directors and financial officials/accountants in manufacturing and nonmanufacturing firms generally agree that NSF's classification of R&D expenditures into basic research, applied research, and development appropriately describes the scope of their companies' self-financed R&D activities (Link 1996).

Definitions

NSF uses the following definitions in its resource surveys. They have been in place for several decades and are generally consistent with international definitions.

- ♦ **Basic research**. The objective of basic research is to gain more comprehensive knowledge or understanding of the subject under study, without specific applications in mind. In industry, basic research is defined as research that advances scientific knowledge but does not have specific immediate commercial objectives, although it may be in fields of present or potential commercial interest.
- ♦ **Applied research**. Applied research is aimed at gaining the knowledge or understanding to meet a specific, recognized need. In industry, applied research includes investigations oriented to discovering new scientific knowledge that has specific commercial objectives with respect to products, processes, or services.
- ♦ **Development**. Development is the systematic use of the knowledge or understanding gained from research directed toward the production of useful materials, devices, systems, or methods, including the design and development of prototypes and processes.
- ♦ **Budget authority**. Budget authority is the authority provided by Federal law to incur financial obligations that will result in outlays.
- ♦ **Obligations**. Federal obligations represent the amounts for orders placed, contracts awarded, services received, and similar transactions during a given period, regardless of when funds were appropriated or payment required.
- ♦ **Outlays**. Federal outlays represent the amounts for checks issued and cash payments made during a given period, regardless of when funds were appropriated or obligated.
- ♦ **R&D plant**. Federal obligations for R&D plant include the acquisition of, construction of, major repairs to, or alterations in structures, works, equipment, facilities, or land for use in R&D activities at Federal or non-Federal installations.

Figure 2-15.
National R&D funding, by character of work



See appendix tables 2-7, 2-8, 2-11, 2-12, 2-15, and 2-16.

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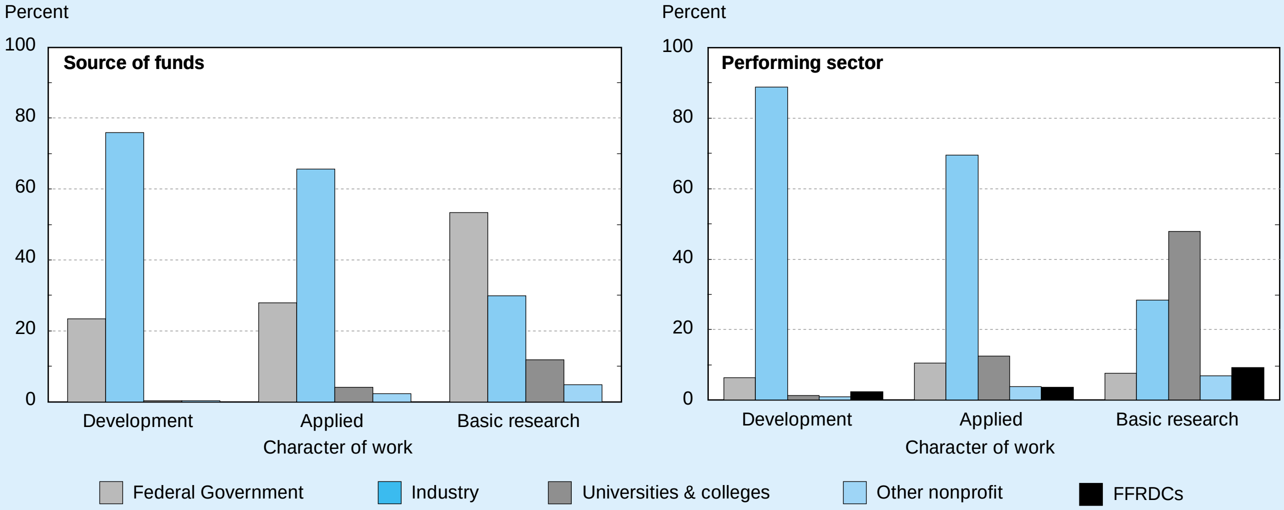
totals reflect continuous increases over several years. In particular, since 1980 there has been a 4.7 percent annual increase, in real terms, in basic research; a 3.9 percent increase in applied research; and a 3.4 percent increase in development. As a share of all 1998 R&D performance expenditures, basic research represented 16.7 percent, applied research 22.5 percent, and development 60.8 percent. These shares have not changed very much over time. For example, in 1980 basic research accounted for 13.9 percent, applied research 21.7 percent, and development 64.3 percent.

Basic Research

In 1998, basic research expenditures reached $37.9 billion. (See text table 2-1.) The annual growth rate of basic research performance has changed over time, but not as dramatically as total R&D. This annual rate, adjusted for inflation, had an average as high as 5.2 percent between 1980 and 1985; the growth rate slowed to 4.4 percent between 1985 and 1994 and increased to 5.0 between 1994 and 1998.

In terms of support, the Federal Government has always provided the majority of funds used for basic research. (See figure 2-16 and appendix table 2-9.) The Federal share of funding for basic research as a percentage of all funding, however, has dropped—from 70.5 percent in 1980 to a 53.4 percent ($20.2 billion) in 1998. (See figure 2-17.) This decline in the Federal share of basic research support does not reflect a decline in the actual amount of Federal support, which grew

Figure 2-16.
National R&D expenditures, by source of funds, performing sector, and character of work: 1998



See appendix tables 2-7, 2-9, 2-11, 2-13, 2-15, 2-16, and 2-17.

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3.1 percent per year in real terms between 1980 and 1998. Rather, it reflects a growing tendency for the funding of basic research to come from other sectors. Specifically, from 1980 to 1998, non-Federal support for basic research grew at the rate of 7.4 percent per year in real terms.

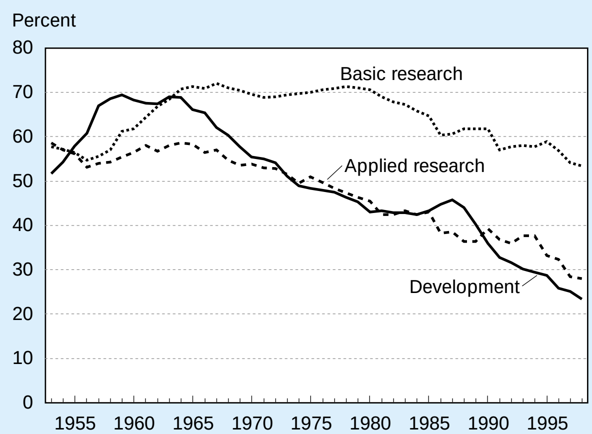
With regard to the performance of basic research in 1998, universities and colleges (excluding FFRDCs) accounted for the largest share—47.8 percent ($18.1 billion). Their performance of basic research has increased, on average, 4.6 percent annually in real terms since 1980. When the performance of university-administered FFRDCs is included, the academic sector's share climbs to 55.0 percent. In 1998, the Federal Government provided 62.1 percent of the basic research funds used by the academic sector. Non-Federal sources—including industry, state and local governments, universities and colleges themselves, and nonprofit organizations—provided the remaining 37.9 percent.

Applied Research

Applied research expenditures were $51.2 billion in 1998. Applied research is performed much more by nonacademic institutions. These expenditures have been subject to greater shifts over time, as a result of fluctuations in industrial growth and Federal policy. Applied research experienced an average annual real growth of 7.2 percent between 1980 and 1985, followed by very low growth of 0.8 percent between 1985 and 1994; the rate of growth rose again to 6.8 percent between 1994 and 1998. Increases in industrial support for applied research explains this recent upturn. Industrial support accounted for 65.6 percent ($33.6 billion) of the 1998 total for applied research; Federal support accounted for 28.0 percent ($14.3 billion).

During the 1980s, Federal support for applied research was intentionally deemphasized in favor of basic research. Even with the current administration's greater willingness to support generic/precompetitive applied research, Federal funding in 1998 for applied research was only 70.8 percent of that for basic research ($14.3 billion versus $20.2 billion, respectively), as reported by research performers.

Figure 2-17.
Federal share of total U.S. funding of basic research, applied research, and development



See appendix tables 2-9, 2-13, and 2-17.

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With regard to performance, 69.9 percent (accounting for $35.8 billion) of the Nation's applied research was performed by industry and industry-administered FFRDCs in 1998. Federal sources funded 28.0 percent ($14.3 billion) of the Nation's applied research.

In the same year, most of the Nation's nonindustrial applied research was performed by universities and colleges and their administered FFRDCs ($7.9 billion) and the Federal Government ($5.4 billion). With regard to Federal intramural applied research, in FY 1998 23.6 percent was performed by DOD, another 23.4 percent by HHS, and 11.5 percent by NASA.[28] Total Federal applied research performance has been remarkably level for more than 30 years, experiencing only a 0.6 percent average annual growth, in real terms, since 1966.

Development

Expenditures on development in 1998 totaled $138.1 billion. Most R&D expenditures are on development. Therefore, historical patterns of development expenditures mirror historical patterns of total R&D expenditures. From 1980 to 1985, development grew on average by 7.0 percent per year in real terms as increasingly larger shares of the national R&D effort were directed toward R&D supported by DOD (which tends to be approximately 90 percent development). (See figure 2-18.) Between 1985 and 1994, on the other hand, development in real terms grew at an average annual rate of only 0.4 percent—from $74.5 billion in 1985 to $103.1 billion in 1994. Between 1994 and 1998, annual growth was back up to 5.7 percent in real terms, to $138.1 billion in 1998—of which 75.8 percent was supported by industry and 23.4 percent by the Federal Government.

In terms of performance, industry (including industrial FFRDCs) accounted for 89.9 percent ($124.1 billion) of the nation's 1998 development activities. The Federal Government accounted for 6.4 percent ($8.8 billion), and all other performers account for 3.7 percent ($5.2 billion).

[28]These percentages are derived from preliminary Federal obligations as reported in NSF (1999a).

Federal Obligations for Research, by Field

Federal Obligations for Basic Research

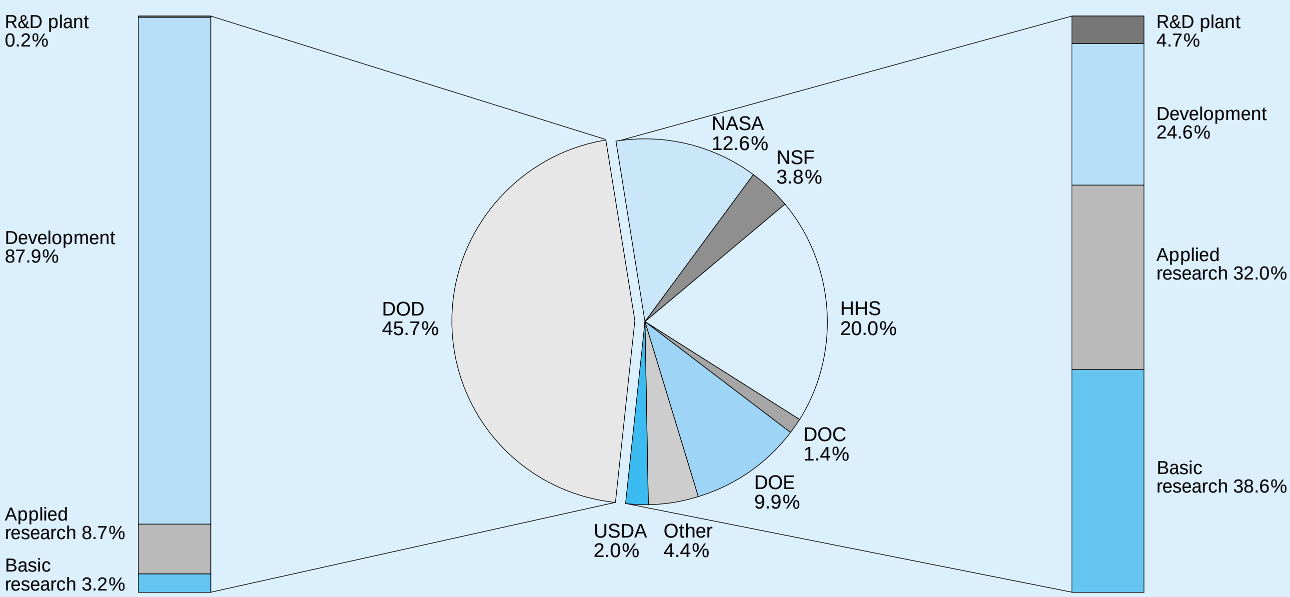
Among fields receiving Federal research support, life sciences garner the largest share of basic and applied research obligations. (See appendix table 2-47.) In FY 1999, an estimated $8.3 billion was obligated for basic research in the life sciences (which includes the biological, medical, and agricultural subfields)—nearly half the basic research total of $16.9 billion. This level of funding has grown steadily since the mid-1980s, although growth in real terms was stagnant from 1993 to 1995 (consistent with the growth pattern for all of HHS, the major funding agency for life sciences). By preliminary estimates, Federal support for basic research in the life sciences has grown rapidly between FY 1997 and FY 1999(averaging 6.2 percent per year in real terms. (See figure 2-20 and appendix table 2-47.)

DOE is the largest provider of funding for basic research in the physical sciences. According to preliminary estimates, DOE provided $1,358 million of a total of $3,305 million in FY 1999; NASA provided $972 million, and NSF provided $551 million (devoted to a wide variety of fields). Federal support for basic research in the physical sciences grew in real terms from 1985 to 1991, then declined from 1991 to 1996, and has since been rising again. (See figure 2-20.)

Federal Obligations for Applied Research

Life sciences received the largest Federal support for applied research: an estimated $6.1 billion in FY 1999 (38 percent of the $16.1 billion total). Engineering received the next largest share, with $4.3 billion in obligations (27 percent of

Figure 2-18.
Projected Federal obligations, by agency and character of work: 1999



See appendix tables 2-27, 2-29, 2-31, and 2-33.

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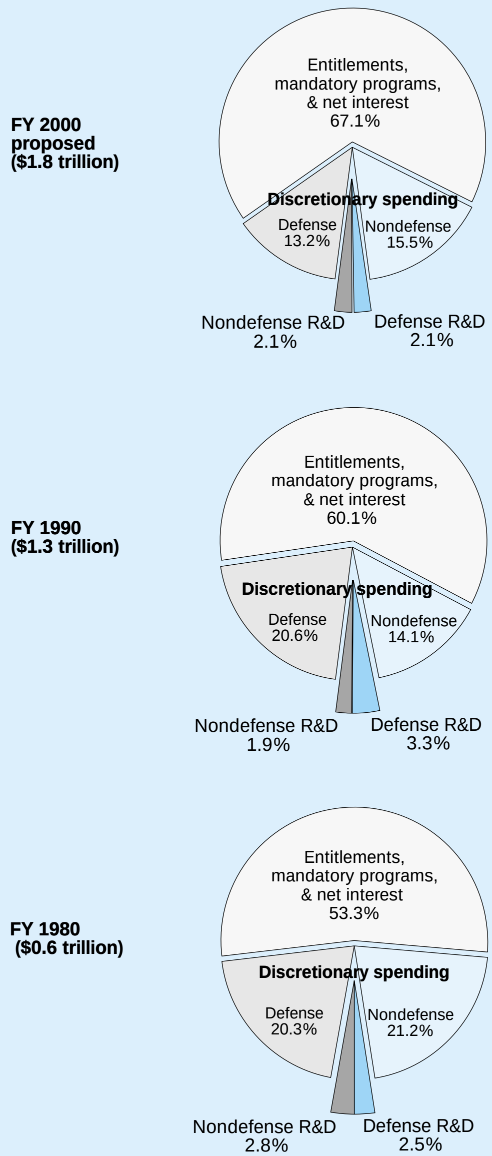
R&D Continues to Fare Well Despite Fiscal Austerity

Reducing the deficit has been an overriding goal of Congress and the Clinton Administration. To gain a better understanding of the difficulty involved in accomplishing this objective, it is helpful to split total Federal spending into two categories—"mandatory" and "discretionary." Certain program expenditures—including those for Social Security, veterans' benefits, Medicare, Medicaid, and interest on the national debt—are considered mandatory items in the Federal budget. That is, the government is already committed by law to finance those programs at certain levels and cannot cut them without a change in the law through an act of Congress. In contrast, discretionary items, including R&D programs, do not enjoy the same level of protection from budget-cutting proposals; the Federal Government does not have to, or is not already committed by law to, finance such programs at particular levels.

In FY 2000, mandatory programs (including interest on the national debt) are expected to account for 67 percent of total Federal outlays. (See appendix table 2-22.) Despite the vulnerability of R&D as a component of discretionary spending, Federal support for R&D has received bipartisan support and has fared well during the fiscal austerity of the past two decades. (See figure 2-19.) For example, an examination of R&D as a percentage of the total Federal budget reveals the following:

- ♦ Although all Federally funded R&D is expected to fall from 5.2 percent of the budget in 1990 to 4.3 percent in 2000, nondefense R&D as a percentage of the total budget is expected to rise slightly—from 1.9 percent in 1990 to 2.1 percent in 2000.
- ♦ As a proportion of total discretionary outlays, R&D increased from 11.5 percent in 1980 to 13.1 percent in 1990 and is expected to be 13.0 percent in 2000.
- ♦ Nondefense R&D as a percentage of nondefense discretionary spending has been holding fairly steady since 1980, at just less than 13 percent.

Figure 2-19.
R&D share of the Federal budget

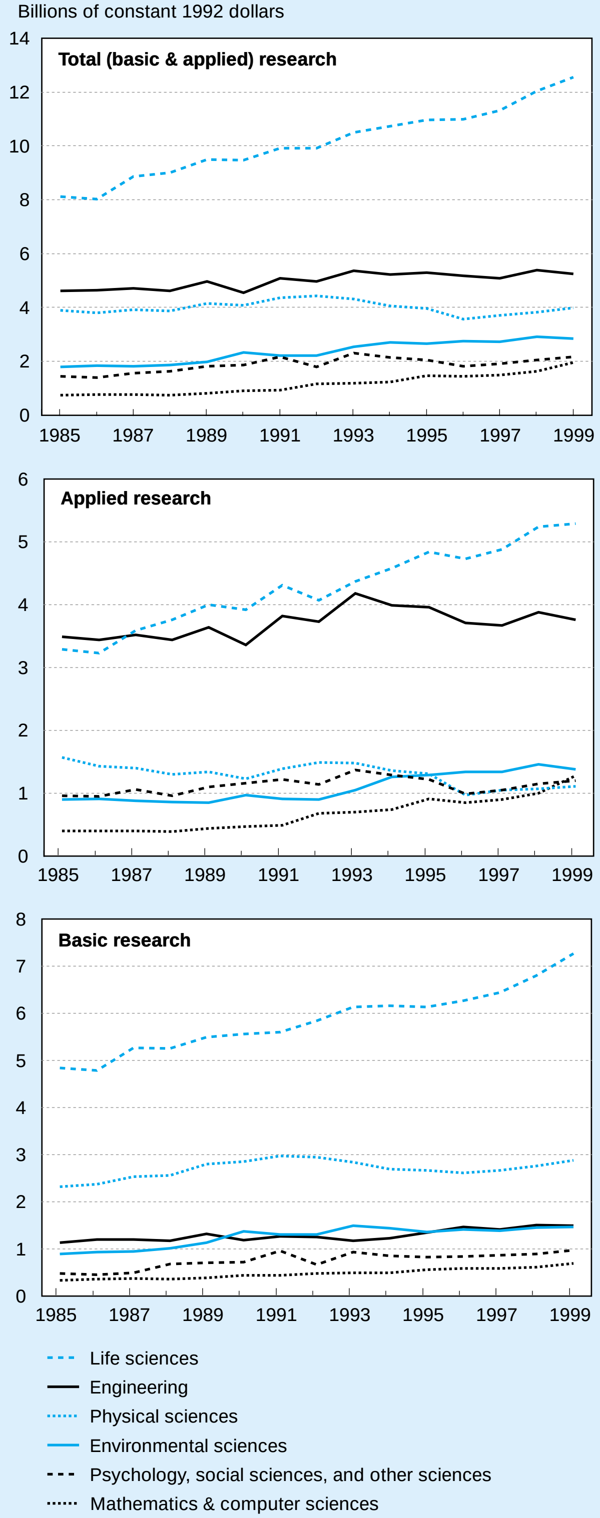


SOURCE: AAAS, *Research and Development: FY 2000*.

See appendix table 2-22. *Science & Engineering Indicators – 2000*

the total). In real terms, Federal support for applied research in the life sciences has grown substantially between 1985 and 1999 (from $3.3 billion to $5.3 billion in constant 1992 dollars. Federal support for applied research in mathematics and computer sciences has experienced particularly strong growth over the same period, from $402 million to nearly $1.3 billion in 1992 dollars. In contrast, Federal support for applied research in engineering, psychology, social sciences, and other sciences has grown very little or decreased slightly in real terms over the same period. Environmental sciences showed moderate growth between 1985 and 1999, from $898 million to nearly $1.4 billion in 1992 dollars. Federal support for applied research in the physical sciences, however, showed a decline in real terms—from $1.6 billion to $1.1 billion in 1992 dollars. On the other hand, Federal support for the physical sciences had been rising since its low of $966 million (in constant 1992 dollars) in 1966.

Figure 2-20.
Federal obligations for research by field: basic research, applied research, and total research



See appendix tables 2-47 and 2-48.

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Federal Obligations for Research (Basic and Applied)

Considering basic and applied research together, the growth of Federal support for research the life sciences vis-a-vis research in other fields is even more pronounced. (See figure 2-20.) In terms of rates of growth, Federal support for research in mathematics and computer sciences has grown rapidly as well.[29]

Cross-Sector Field-of-Science Classification Analysis

A challenging, open-ended—yet promising—method of classifying R&D expenditures, in various sectors in addition to academia, is by field of science. Such classification, applied to historical data, indicates how R&D efforts in various fields of science and engineering have grown in economic importance over time. This information is potentially useful for science policy analysis and for planning and priority-setting. Moreover, scientists and engineers themselves can benefit from information about how R&D expenditures in various fields of science and engineering have evolved over time. For example, such information might influence decisions by scientists and engineers—and science and engineering students—about taking on new research endeavors or exploring new career opportunities.

Classification of academic R&D by field of science is provided in detail in chapter 6 of this report. The only additional sector for which extensive data by field exist is the Federal Government. Industrial R&D—which represents three-quarters of all R&D performed in the United States—has not been subdivided by field of study, for three reasons: (1) Unlike research performed by universities and Federal agencies, much of the research by private firms is confidential (for obvious reasons), and the provision of such information might compromise that confidentiality; (2) most private companies do not have the accounting infrastructure in place to compile such statistics, so any efforts on their part to provide this additional information could be significantly burdensome to them; and (3) much of the R&D carried out by industry is interdisciplinary, especially at the development stage (e.g., the development of a new vehicle would involve mechanical engineering, electrical engineering, and other fields)—which in many cases might make the splitting of R&D by field somewhat arbitrary. Therefore, the collection of such data is unlikely.

Nonetheless, some analysis along these lines, wherever possible, could shed light on overall levels of R&D support for general lines of inquiry. The analysis that follows circumvents this problem by grouping fields with standard industrial categories, creating nine general categories of R&D that can be associated with fields of science and engineering and with related industrial categories.

[29]For much more detailed data on Federal support by field of science, see Board on Science, Technology, and Economic Policy (1999).

R&D in Chemistry, Life Sciences, and Information Technology

In this section, R&D is categorized into three broad areas; each area is associated with academic fields of study and with industrial end-products that tend to be associated with those fields. For easier data interpretation, all academic and Federal fiscal year data were converted to calendar year data so they would be comparable to data pertaining to industry categories (which are collected and provided on a calendar year basis). Furthermore, all dollar amounts in this section are in real (constant 1992) terms, thereby allowing the analysis to focus on effects that are independent of inflation.

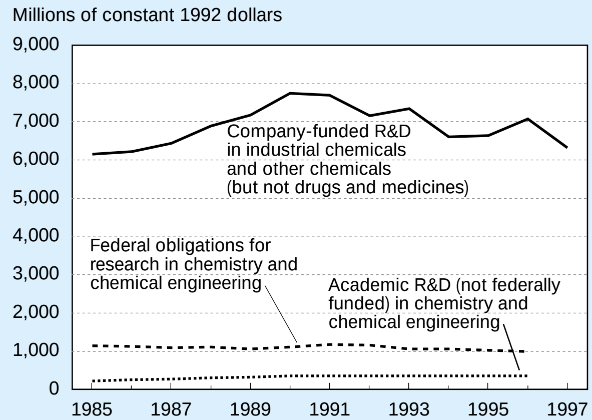
Chemistry (Nonmedical) and Chemical Engineering

Three categories of R&D were identified that could be associated primarily with chemistry and chemical engineering. (See figure 2-21 and appendix table 2-49.) These categories exclude chemistry associated with medicine, which was included instead under the broad category of life sciences. The largest of these categories, by far, is company-funded R&D in industrial chemicals and other chemicals (but not drugs and medicines). In real terms, expenditures in this category grew from $6.1 billion in 1985 to $7.7 billion in 1990 and then eventually declined, on average, to $6.3 billion in 1997—only slightly higher than the level 12 years earlier. The next two categories were much smaller. Federal obligations for research in chemistry and chemical engineering remained at roughly $1 billion (in constant 1992 dollars) throughout the 1985–96 period. The smallest category—academic R&D (not Federally funded) in chemistry and chemical engineering—grew steadily in real terms, from $223 million in 1985 to $361 million in 1996.

Life Sciences

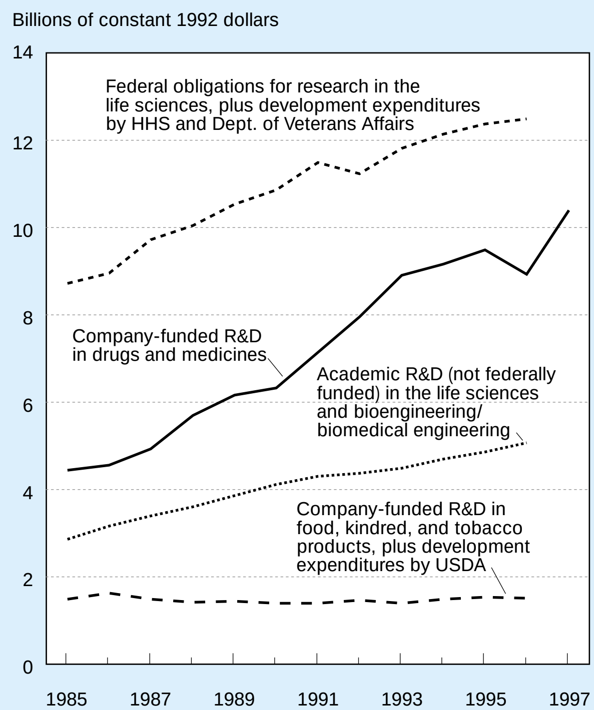
R&D in the broad area of the life sciences is characterized by strong and fairly-continuous real growth in its three largest categories. (See figure 2-22 and appendix table 2-50.) The largest category, Federal obligations for research in the life sciences, increased from $8 billion in 1985 to $11 billion in 1996. Company-funded R&D in drugs and medicines grew dramatically in real terms, from $4 billion in 1985 to $10 billion in 1997. Likewise, academic R&D (not Federally funded) in the life sciences and bioengineering/biomedical engineering grew continuously, from $3 billion in 1985 to $5 billion in 1996. Real growth in R&D also occurred in development expenditures by HHS and the Department of Veterans Affairs. With regard to food and other agricultural products that are also associated with life sciences, real growth occurred in the relatively small levels of development expenditures by USDA (from $41 million to $77 million between 1985 and 1996), but very little real change occurred in company-funded R&D in food, kindred, and tobacco products (which grew from $1.4 billion to $1.6 billion between 1985 and 1997).

Figure 2-21.
R&D associated primarily with chemistry (nonmedical) and chemical engineering



See appendix table 2-49. *Science & Engineering Indicators – 2000*

Figure 2-22.
R&D associated primarily with the life sciences

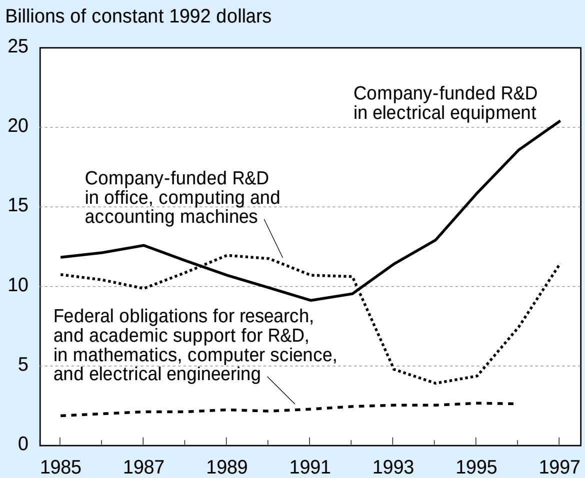


See appendix table 2-50. *Science & Engineering Indicators – 2000*

Mathematics, Computer Science, and Communication and Electrical Equipment

Although seven categories of R&D fall under this broad area, two clearly dominate the others in terms of the magnitude of their expenditure levels. (See figure 2-23 and appendix table 2-51.) The largest area, by 1997, was company-funded R&D in electrical equipment, which held steady at

Figure 2-23.
R&D associated primarily with mathematics, computer science, and communication and electrical equipment (excluding DOD-supported development of military equipment)



See appendix table 2-51. *Science & Engineering Indicators – 2000*

close to $10 billion (in constant 1992 dollars) throughout 1985–92, after which it doubled to more than $20 billion by 1997. The second-largest category in 1997—company-funded R&D in office, computing and accounting machines—remained at or above $10 billion between 1985 and 1992 as well. It then fell sharply in 1993 to below $5 billion but recovered between 1995 and 1997; by 1997 it represented more than $11 billion in R&D. The third-largest category, Federal obligations for research in mathematics and computer science, grew from $745 million in 1985 to nearly $1.5 billion in 1996. Federal obligations for research in electrical engineering (not Federally funded) declined from $813 million to $601 million over the same period. Three small academic categories—R&D in mathematics, computer science, and electrical engineering—each nearly doubled in real terms between 1985 and 1996.

Inter-Sector and Intra-Sector Domestic Partnerships and Alliances

In the performance of R&D, organizations can collaborate, either within the same sector (e.g., a partnership between firms) or between sectors (e.g., a partnership between a firm and the Federal Government). Decisions by organizations to form these partnerships are based on economic considerations, legal and cultural frameworks, scientific and technological conditions, and policy environments.

Economic Considerations Underlying R&D Partnerships

Collaboration allows individual partners to leverage their resources, reducing costs and risks and enabling research ventures that might not have been undertaken otherwise. In the case of intra-sector collaboration, the underlying theme is that more can be accomplished at lower cost when resources are pooled, especially if organizations can complement each other in terms of expertise and/or research facilities. For private companies, another advantage of partnerships is that they reduce (or eliminate) competition between the allied companies, which may thereby enjoy higher profits once their jointly developed product is marketed.

With regard to university-industry alliances, companies can benefit from the extensive research infrastructure (including the students), as well as the store of basic scientific knowledge, that exists at universities—which those firms would not be able afford on their own.[30] Universities, on the other hand, benefit from alliances with firms by being better able to channel academic research toward practical applications" (Jankowski 1999).

In the case of collaboration between Federal laboratories and industry—in the form of Cooperative Research and Development Agreements (CRADAs)—a wide range of economic benefits to both parties have been noted. The main reason for the creation of CRADAs was that industry would benefit from increased access to government scientists, research facilities, and the technology they developed. Government, in turn, would benefit from a reduction in the costs of items it needs to carry out its objectives (Lesko and Irish 1995, 67). Both would benefit from technology transfer, and Federal R&D in national labs would be more useful to U.S. industry. Some analysts have argued as well that Congress created CRADAs[31] to simplify negotiations between the Federal Government and industry in the process of technology transfer, by making the process exempt from Federal Acquisition Regulation (FAR) requirements.

With regard to collaboration between academia and the Federal Government, little exists in the strict sense of employees from both working together, side-by-side, on R&D projects. On the other hand, collaboration in a broad sense is quite extensive in that academia receives research grants to perform "targeted research."[32] (See "Federal Support to Academia.") Some of this research is designed to meet Fed-

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[30]On the topic of firms benefiting from the tacit knowledge of universities, Prabhu (1997)—citing earlier work by Tyler and Steensma (1995)—suggests, "The greater the tacitness of technology (hard to document in writing, residing in individuals, systems and processes of the firm, and difficult to transfer through market mechanisms), and the greater the complexity of technology (variety and diversity of technologies that must be incorporated into the development process), the more likely it is that executives will consider technological collaboration a mode of technology development."

[31]See the next section on the legal reasons for partnerships and alliances.

[32]Targeted research as a policy goal is discussed in U.S. Congress, House Committee on Science (1998).